Silicon Nitride Material Integration for Enhanced Photonic Functionalities

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Abstract: We demonstrate a novel material integration scheme for the realisation of wavelength division multiplexing devices in the O-band and discuss advanced fabrication methods for the realisation of nonlinear devices for all-optical processing in the C-band.

1. Introduction

Silicon photonics has accelerated the development of photonic integrated circuits (PICs) using the silicon-on-insulator (SOI) platform [1]. Nevertheless, the applications for PICs have broadened to areas in which the intrinsic material properties of silicon pose challenges. Therefore, research efforts have geared towards the development of CMOS compatible materials with back-end-of-line (BEOL) integration that can bridge the gap and complement silicon to achieve enhanced functionalities and high integration density.

Silicon nitride (SiN) has become a material widely used for PICs, due to its full CMOS compatibility and its flexible optical properties that can be engineered to demonstrate linear, non-linear and active devices for a wide range of applications [2, 3]. With a refractive index that can be tuned between 1.7 and 3.1 [3, 4], it provides a moderate optical confinement that represents a trade-off between device footprint and level of integration enabling low propagation losses. Moreover, it has a low thermo-optic coefficient (10^{-5} °C^{-1}) and negligible two-photon absorption (TPA) in the NIR, useful for nonlinear applications and devices with high temperature stability [5, 6].

In this paper, we use an advanced material integration scheme for the realisation of polarisation insensitive coarse wavelength division multiplexing (CWDM) devices in the O-band that can be seamlessly integrated with a thick SOI platform. Additionally, we discuss the realisation of waveguides and devices with enhanced nonlinear properties for all-optical processing in the C-band.

2. SiN/SOI integration for CWDM

The large birefringence of sub-micrometer scale silicon waveguides poses significant limitations to the operation of communication devices. This is especially so in the case of wavelength division multiplexing (WDM) applications, in which the polarisation state of the received signals may vary independently of each other. Additionally, the low temperature stability of SOI-based devices, originating from the high thermo-optic coefficient of silicon (10^{-4} °C^{-1}), and the potential of introducing significant phase errors during fabrication, due to the large refractive index contrast typical of SOI waveguides, may further hinder the implementation of future silicon WDM systems.

In order to address these challenges, we demonstrate the monolayer integration of SiN (de)multiplexer devices with thick SOI waveguides for CWDM systems operating in the O-band (1260-1360 nm). This is achieved through a novel butt-coupling integration scheme between micro-meter scale SiN and SOI waveguides based on N-rich SiN layers with a refractive index of 1.88 at 1310 nm deposited through a BEOL compatible low-temperature plasma enhanced chemical vapour deposition (PECVD) process (<400 °C) [4]. Fig. 1a shows that this approach allows introducing the SiN (de)multiplexer into a SOI circuit without impacting the response of the device, which still exhibits an insertion loss close to 2 dB and 1 dB bandwidth cross-talk <21 dB. Compared to other SiN-on-SOI integration techniques, this approach provides a high optical confinement that dramatically reduces the birefrengence of the waveguides allowing the realisation of polarisation independent CWDM devices. Moreover, the concept can be extended to integrate seamlessly active devices with thick material stacks that are hard to integrate with the typical thin SOI geometries.

3. Si-rich SiN Integration for Nonlinear Applications

Although the SOI platform has enabled the demonstration of nonlinear devices for all-optical signal processing, its high nonlinear losses due to two photon and free carrier absorption at wavelengths below 2 μm hinder the

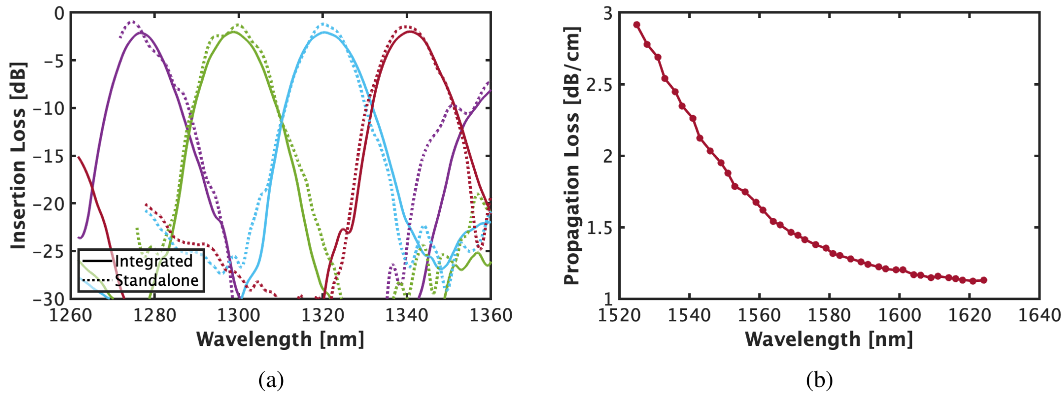

Fig. 1: (a) Spectral response of a micro-meter scale SiN (de)multiplexer integrated with SOI waveguides compared against its standalone counterpart. (b) Propagation loss of Si-rich SiN waveguides in the C-band.

performance of these devices. We have previously demonstrated that the nonlinear Kerr coefficient of SiN can be enhanced by increasing its silicon content to achieve a Si-rich composition with a refractive index of 2.54 at 1550 nm [6]. This enhancement can be attained without incurring in TPA or further increase the linear propagation losses in the C-band by using the low-temperature PECVD deposition process described in [4, 6].

We have extended the use of this deposition method to a highly scalable fabrication process on 200 mm wafers that has enabled the realisation of Si-rich waveguides with a refractive index of 2.41 at 1550 nm and propagation losses <2 dB/cm at >1550 nm. Since the propagation loss exhibits a strong dependence to wavelength due to the absorption of the material, especially at shorter wavelengths (Fig. 1b), a further optimisation study is being conducted to identify additional steps that can be performed to decrease the losses below 1 dB/cm across the whole of the C-band. In a similar manner, we have worked on developing the fabrication processes required to achieve high efficiency in-plane and out-of-plane coupling schemes into the non-linear waveguides. These building blocks will enable the future demonstration of fully integrated four-wave-mixing based wavelength conversion and phase-sensitive amplification modules for all-optical signal processing.

4. Conclusions

Advanced material integration schemes enable the incorporation of SiN to bridge the gap and complement the SOI platform for the realisation of enhanced linear and nonlinear functionalities. These include polarisation insensitive (de)multiplexers for WDM systems and low-loss nonlinear devices for all-optical processing.

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